COMMUNICATIONS

Initial bias dependency in dc drift of z-cut $LiNbO_3$ Optical intensity modulators

Hirotoshi Nagata
Sumitomo Osaka Cement Co., Ltd.
Optoelectronics Research Division
New Technology Research Laboratorles
585 Toyotomi-cho, Funabashi-shi
Chiba 274-8601 , Japan
E-mail: hinagata@sits.soc.co.jp

Hideki Honda
Katsuya Akizuki
Sumitomo Osaka Cement Co., Ltd.
Optoelectronics and Electronics Division
585 Toyotomi-cho, Funabashi-shi
Chiba 274-8601 , Japan

Subject terms: modulators; dc; LiNb03

Paper 990237 received June 1 4, 1 999; revised manuscript received Nov. 4, 1999; accepted for publication Nov. 30, 1999.
[S0091-3286(00)03004-X]

1 Introduction

Estimation of a long-tenn dc drift behavior is essential for the application of $LiNbO_3$ optical intensity modulators to fiber communication systems. Therefore temperature-accelerated tests are carried out using a feedback-bias-control operation system, and the results are converted into a duration at ordinary device operation temperatures, e.g., 50ºC. The activation energy E_a for the data conversion was reported to be about I eV for z-cut $LiNbO_3$ modulators.[1-3] In the feedback-bias-controlled operation, a certain dc voltage is applied to the ac-driven modulator sample as the initial dc bias, and this applied dc voltage is varied continuously to keep the state of the optical output modulation at the initial state.[3-5] Furthermore, the initial bias voltage set to be the same for all samples is effective in simplifying the device qualification process. However, there is a possibility that the initial dc bias will change, sample by sample, because the bias voltage required to adjust the initial output modulation state depends not only on a device design but also on an initial temperature for the system operation.[5,6] The output modulation states are strongly affected by mechanical fluctuation introduced into devices during the fabrication, and a complete equalization of them is difficult.[6-10] To provide practical information on the long-term drift performance of z-cut $LiNbO_3$ modulators, we carried out experiments to show a relationship between the initial dc bias and the resulting dc drift. Because the z-cut $LiNbO_3$ modulators have been commonly used in both 2.5 and 10 Gbits/s systems, our results should be useful for a quahfication of $LiNbO_3$ devices. As a result, the applied voltage including the dc drift at a certain operation time was found to be proportional to the initial dc bias with an operation-time-dependent factor $A(t) > I$. Then, through a data fitting of temperature-accelerated test results at 120ºC, the ultimate applied dc voltages after the 20 yrs of operation at 50ºC were estimated to be from 10 to 1 5 V due to a change in the initial dc bias from 3.5 to 5.5 V.

2 Experiments and Results

To remove a difference in drift performance caused by device design, 8 pieces of Mach-Zehnder type 10 Gbits/s optical intensity modulators made from the same z-cut $LiNbO_3$ wafer were tested. The unbiased modulators were placed in an oven kept at 120ºC, and after 4 h of storage the modulators reached this temperature and the measurements were started. The initial dc bias was applied individually to each of the ac-driven modulators, and the optical output signal (λ = 1 .55 µm) was monitored. The initial dc bias was set at 3.5 V for one modulator, 4.5 V for two, 5.5 V for two, 6.5 V for two, and 7.5 V for one. The dc voltage applied to each of the modulators was controlled to maintain the optical output modulation at the initial dc biased state (control frequency = I kHz.)

Figure I shows measured results as a relationship between applied dc voltage and device operation time at 120ºC with a linear time axis [Fig. I (a)] and a logarithmic time axis [Fig. 1(b)]. Using E_a= I eV reported for dc drift in z-cut $LiNbO_3$ modulators,[1] the 120 hours at 120ºC can be converted to the 8.2 years at 50ºC for instance. Because the limit of the dc driver used was ±10 V, samples started from higher initial dc biases got to be in an uncontrollable state within a day.

3 Discussion and Long-Term Drift Estimation

Figure 2 reveals the correlation between the applied dc voltage and the initial dc bias obtained after I h (black circles) , 5 h (white circles), and 50 h (black triangles) of operation. Similar results were obtained for other data from different operation times, and the following relationship was found:

$$V_{appl} = A(t)\, V_{initial}. \quad (1)$$

Here, $V_{initial}$ rs the initial dc bias, V_{appl} is the applied dc voltage at time t including the initial dc bias, and A (t) is a proportional factor as a function of the operation time t. The relationship denoted by Eq. (1) is consistent with a fact that unbiased (dc bias =0 V) modulators do not dnft at a constant temperature.[6,11] Furthermore, the proportional factor A (t) was found to be larger than I and increase with

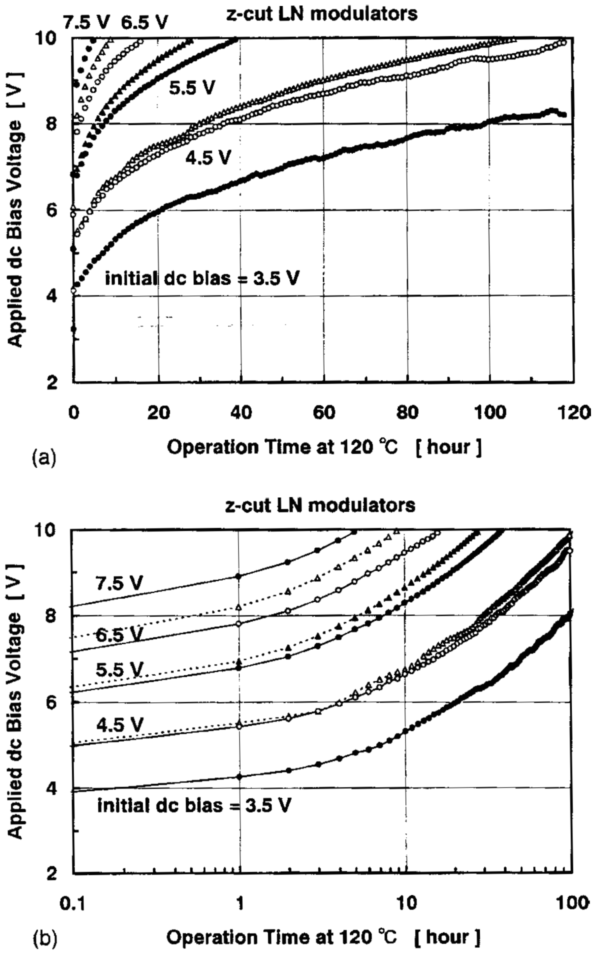

Fig. 1 Feedback-bias-controlled operation results for z-cut $LiNbO_3$ modulators at 120°C with various initial dc biases from 3.5 to 7.5 V with (a) a linear time axis and (b) a logarithmic time axis. The vertical axes denote the applied dc voltage including the initial dc bias.

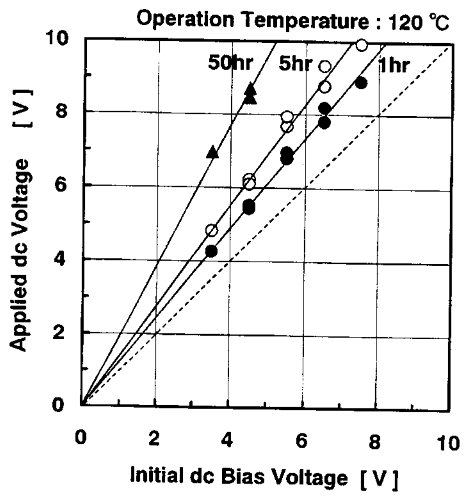

Fig. 2 Relationship between an applied dc voltage and an initial dc bias plotted using the data of the Ist, 5th, and 50th hour in Fig. 1. Solid lines are fifting results obtained by simple proportional equations, and the dashed line denotes a relationship with a proportional factor= 1.

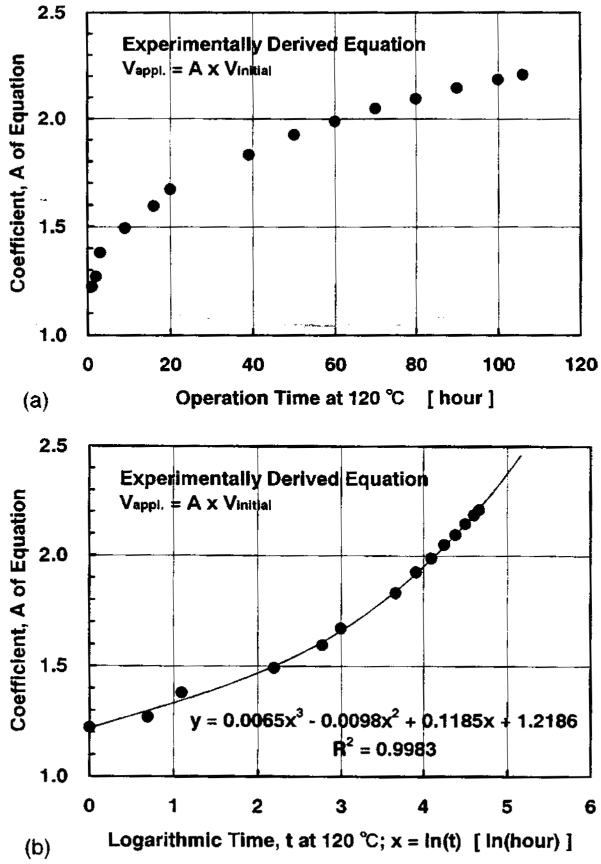

Fig. 3 Operation time dependency of the proportional factor *A(t)* obtained by plots, as show in Fig. 2, with (a) a linear time axis and (b) a logarithmic time axis.

time *t*. This result indicates that the applied dc voltage expands more largely with the factor *A (t)* for devices operated with higher initial dc biases. In other words, the dc drift rate of $LiNbO_3$ modulators depends on the magnitude of the initial dc bias, as we previously suggested. [12,13]

The operation time dependency of the factor *A (t)* is plotted in Fig. 3(a), showing a logarithmic-like change against the time axis at 120ºC. Figure 3(b) reveals a numerical fitting result of the data by an expression of the third order for the logarithmic time axis, In(t). Although a physical meaning of the expression is not currently known, the derived expression can be used to estimate the initial dc bias dependency of the long-tenn drift.

Figure 4(a) denotes the dnft curves calculated using the preceding expressions, in which measured data of Fig. 1 (a) are also plotted. Similar drift curves calculated for the operations at 85 and 50ºC are shown in Figs. 4(b) and 4(c), respectively. In the first step of the calculation, an expression similar to that in Fig. 3(b) for *A (t)* was derived using a new time axis at 85ºC (50ºC), which was converted from 120ºC data using E_a= I eV. Then, the *A(t)* values calculated for certain times at 85 and 50ºC were substituted for Eq. (1), and the applied dc voltages were plotted as the function of time and initial dc bias.

The results of Fig. 3(c) indicate that if the performance of the dc dnver is limited by a 15-V maximum, for in-

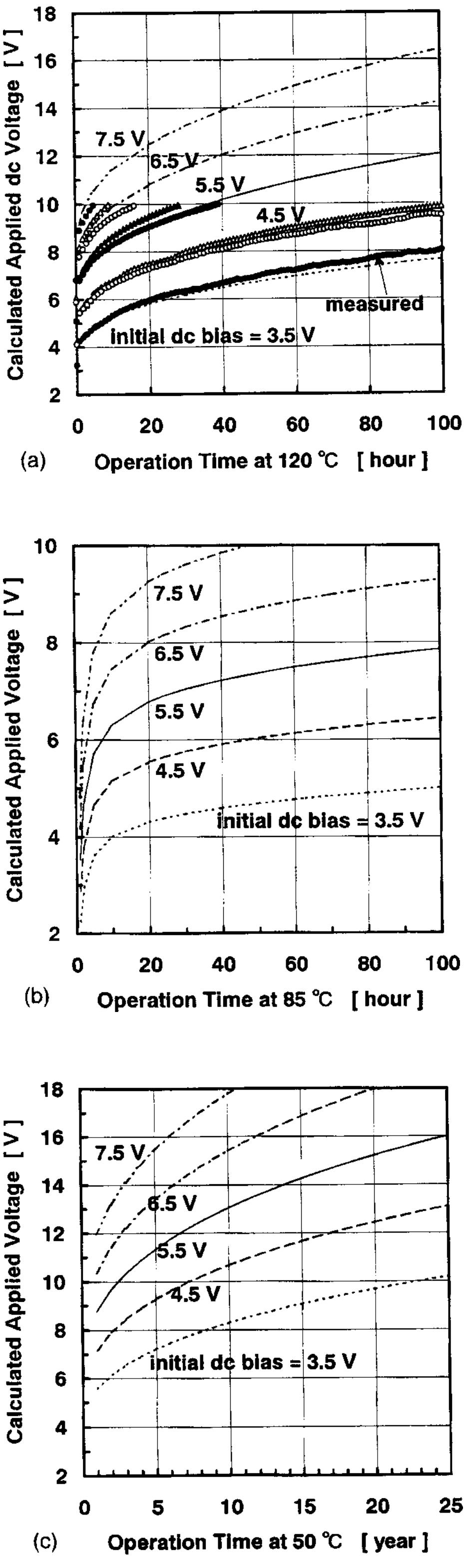

Fig. 4 Initial bias dependency of dc drift of z-cut LiNb03 modulators estimated for operations at (a) 120°C, (b) 85°C, and (c) 50°C. The vertical axis denotes applied dc voltages including both the initial dc bias and the drift.

stance, the initial dc bias applied to $LiNbO_3$ modulators must be set to less than 5.5 V to ensure their 20-yr lifetime at 50ºC. In other words, the total fluctuation of the modulator output due to thermal dnft, modulation half-wave voltage ($V\pi$), initial operating point, etc. must be suppressed below 5.5 V.

4 Conclusion

The initial dc bias dependency of the long-term dc dnft in z-cut $LiNbO_3$ optical intensity modulators was estimated from temperature accelerating test results at 120ºC. The applied dc voltages after 20 yr of operation at 50ºC were estimated to increase from 10 to 15 V due to a change in the initial dc bias from 3.5 to 5.5 V.

References

1. H. Nagata, N. Mitsugi, K. Higuma, J. Ichikawa, T. Sakamoto, T. Fujino, and T. Shinnki, "Reliability of $LiNbO_3$ based integrated optical waveguide devices for fiber communication systems," *Mater. Res. Soc. Symp. Proc.* **531**, 359-370 (1998).
2. M. Seino, T. Nakazawa, Y. Kubota, M. Doi, T. Yamane, and H. Hakogi, "A Iow dc-drift Ti:$LiNbO_3$ modulator assured over 15 years," in *Proc. OFC'92*, pp. 325-328, Optical Society America, Washington, DC (1992).
3. S. K. Korotky and J. J. Veselka, "RC network analysis of long term Ti:$LiNbO_3$ bias stability," J. Lightwave Technol. **14**(12), 2687-2697 (1996).
4. H. Nagata, N. Mitsugi, J. Ichikawa, and J. Minowa, "Materials reliability for high-speed lithium niobate modulators," *Proc. SPIE* **3006**, 301-313 (1997).
5. R. S. Moyer, R. Grencavich, R. W. Smith, and W. J. Minford, "Design and qualification of hermetically packaged lithium niobate optical modulator," *Proc. 1997 Electronic Component and Technology Conf.* pp. 425-429, IEEE, San Jose, CA (1997).
6. D. R. Maack, "Reliability of lithium niobate Mach Zehnder modulators for digital optical fiber telecommunication systems," *SPIE Critical Reviews* **CR73**, 197-230 (1999).
7. H. Nagata, K. Kiuchi, and T. Sugamata, "Refractive index fiuctuations in deformed Ti:$LiNbO_3$ waveguides due to Si02 overlayer deposition," *Appl. Phys. Lett.* **63**(9), 1176-1178 (1993).
8. H. Nagata, S. Oikawa, and M. Yamada, "Comments on fabrication parameters for reducing thermal drift on $LiNbO_3$ optical modulators," *Opt. Eng.* **36**(1), 283-286 (1997).
9. J. Nayer, H. Nagat~ S. Simotsu, S. Oikawa, and M. Yamada, "Modulation characteristics of high-speed optical modulators with properly split asymmetry into their Mach-Zehnder arms," *Electron. Lett.* **31**(5), 387-388 (1995).
10. M. A. Powell and A. O. Donneu, "What integrated optics is really used for," *Opt. Photonics News* **8**(9), 23-29 (1997).
11. H. Nagata, K. Kiuchi, S. Shimotsu, J. Ogiwara, and J. Minowa, "Estimation of direct cunent bias and drift of Ti:$LiNbO_3$ optical modulators," *J. Appl. Phys.* **76**(3), 1405-1408 (1994).
12. H. Nagata, N. Mitsugi, T. Sakamoto, K. Kiuchi, and J. Ichikawa, "Applied-voltage induced fatigue of lithium niobate waveguides," *Appl. Phys. Lett.* **68**(3), 301-303 (1996).
13. N. Mitsugi and H. Nagata, "Hysterisis in dc bias drift of $LiNbO_3$ optical modulators," *Eng. Lab. Notes Opt. Photon. News* **7**(8), (1996).